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Comparison of prediction models for determining energy demand in the residential sector of a country

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ABSTRACT

The increasing need for energy conservation has led to the development of a range of energy models for assessing energy demand in the residential sector of a country. Even though such models deliver a principal solution for forecasting energy demand and assessing the impact of future energy saving measures, collecting the required baseline data is fraught with difficulties such as a complete lack of data, missing data within a dataset and a lack in coherence between different datasets in terms of detail, data collection method, baseline assumptions and sample size. This paper analyses the transferability and accuracy of twelve energy models (MAED-2, FfE-Gebäudemodell, CDEM, REM, CREEM, ECCABS, REEPS, BREHOMES, LEAP, DECM, CHM, BSM), taking Germany as case study example. Furthermore, a sensitivity analysis is conducted for each model to analyze the significance of the input variables for the overall modelling outcome, highlighting the most influential variables. It is shown that models with a high level of disaggregation do not necessarily guarantee more accurate results. Adjustments are proposed to improve the transferability of the models to the case study country Germany.

1. Introduction

Over the last two decades, the world's total primary energy use across all sectors (industrial, residential, commercial, transport, agricultural) has grown by 49% with an average annual increase of about 2% [1] and currently stands at 560 EJ per year [2]. A considerable part of the global energy use is attributable to the residential sector. In the European Union (EU), the residential sector is responsible for about 26% of the total final energy use [3] and it is estimated that, overall, the residential sector represents about one third of the world's energy use [4]. However, on a national level the share varies depending on the conditions of the individual country and can reach up to 50% for selected countries [5,6].

The progressive increase and the overall high level of energy use in the residential sector contribute to the depletion of fossil fuel resources, put stress on the supply side of energy services, potentially create energy security issues and have environmental impacts locally as well as globally [7]. Therefore, it is generally agreed that energy saving policy measures in this sector present a great potential for reducing energy use and hence CO_2 emissions related to the combustion of fossil fuels [8]. The residential sector can, therefore, provide an important contribution to meeting climate and energy conservation targets such as the "20-20-20" target in the EU, which, by 2020, aims at a 20% reduction in greenhouse gas (GHG) emissions from a 1990 baseline, a 20% share of renewable energy in the final energy use and a 20% energy efficiency improvement compared to projections made in 2007 for 2020 [9–11].

However, for the evaluation of energy saving policies as well as incentives for meeting greenhouse gas emission targets, information about the potential future development of the energy demand as well as the variables that affect the actual use and could potentially influence future demand is needed [12,13]. In recent years various models have been developed for this very reason, which allow for a quantitative assessment of both, the current energy use as well as, based on the impact of different policy measures, a prediction of the future energy demand of a country [14]. Energy models where the calculation routines are publicly available and that are applicable to the residential sector include the following twelve models: MAED-2 [15], FfE-Gebäudemodell [16], CDEM [17], REM [14], CREEM [18], ECCABS [19,20], REEPS [21], BREHOMES [22], LEAP [23], BSM [24], DECM [25] and CHM [26]. These models, which are detailed in Table 1, are assessed in the following, looking at the underlying modelling approach as well as their performance for

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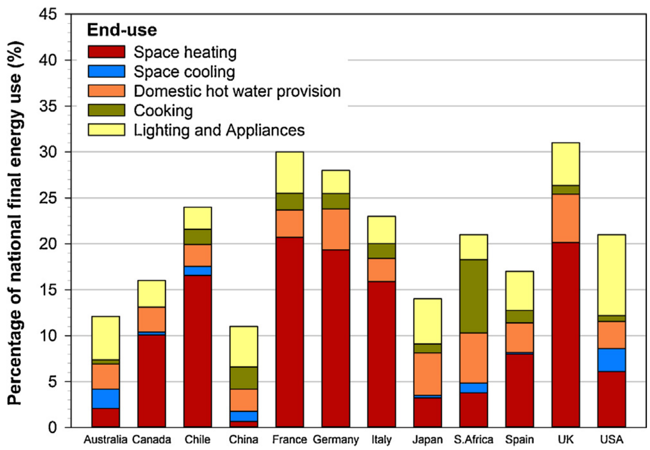

Fig. 1. Share of the residential sector in the national final energy use according to final use. (Data sources: [35–46], Note: The baseline years for the data are 2013 for the UK, Germany, the USA and Australia; 2011 for Italy and Spain; 2010 for Canada; 2009 for South Africa and France and 2008 for Chile and China. In the case of Canada 'Cooking' is included under "Lighting and Appliances". For France, Germany, Italy and the UK "Space cooling" is included under "Lighting and Appliances").

predicting the energy demand in the residential sector for the case of Germany.[1]

2. Issues with current energy models for predicting energy demand in the residential sector

Although residential energy models are an appropriate solution for predicting energy demand and assessing the impact of future energy saving measures in this sector, the diversity of existing modelling methods makes it difficult to select an appropriate model for assessing the development in a given country. Currently, there are a limited number of energy models which can, in principle, be used for any country. This includes, for example, the models LEAP [23] and MAED-2 [15]. However, considering that each country represents a particular case in terms of the share of the residential energy use compared to the total energy use as well as the share of different final energy uses within the residential sector, the results produced with these models may not be equally valid for all countries. This problem is highlighted in Fig. 1 which shows that there are large variations in the share of final energy uses in the residential sector, depending on the climate, economy, living standard, lifestyle and equipment that is used in different countries. Therefore, for a number of countries individual models have been developed that are specifically tailored towards the local conditions with respect to their computational routines. The models BREHOMES [22] for the UK and CREEM [18] for Canada are examples for this approach. However, it remains unclear, whether such models that were developed for a specific country are transferrable and what adjustments would be necessary to obtain an accurate estimate of the energy demand in a different country than the one that they were designed for.

In addition, each model has a different level of disaggregation and, therefore, a different level of detail is needed in the input data. Models with a high level of disaggregation allow a greater understanding of the influence of various input parameters. However, the data collection which is usually done through statistical analyses [5] may, in some cases, be fraught with difficulties due to the difference in detail of the underlying data bases [16] or, in other cases, may force policy developers to put a further level of detail to the existing baseline information [37]. This ultimately slows the modelling process. By contrast, models that do not have a high level of detail may underestimate or even completely miss the impacts of a specific energy saving measure. This could potentially have an adverse effect on decision making when assessing the predicted implications of a policy measure. For example, prediction models like LEAP [23], or the FfE-Gebäudemodell [16] cannot take into account a reduction in energy demand that is induced by an improved thermal insulation. However, in the case of Germany, the continued development in the field of thermal insulation materials [47] and the introduction of the so-called "Wärmeschutzverordnung" (Thermal Insulation Regulation) in 1977 with amended versions in 1984 and 1995 and the subsequent "Energieeinsparverordnung" (EnEV, Energy Saving Regulation) published in 2002 with a major revision in 2007 resulted in a continuous decline in the average final energy use in new buildings over the last decades [48,49].[2] This reduction in final energy use is mainly related to reduced space heating requirements [50] as a result of both technology changes in space heating provision and improved thermal insulation standards. This highlights the need for defining the optimum input variables to facilitate simulation and at the same time maintain a high level of accuracy in the predictions.

The accuracy of the currently available residential energy models has typically been tested, but most of the existing models, apart from the models CDEM [17], DECM [25], CHM [51] and BSM [24], have not been subjected to studies looking at the effect of the input variables on the uncertainty in model prediction [25,51]. The accuracy of the models was, in general, determined for specific countries with this assessment being mostly limited to the country for which they were initially developed, comparing the prediction results with national statistical data [17]. However, this approach does not give any indication of the ability of these models to predict energy demand in other countries which raises the question of model transferability. The model uncertainty for the CDEM, DECM, CHM and BSM models was quantified through a sensitivity analysis which identified the input variables with the greatest effect on the models' outputs [17]. Firth et al. [17], Cheng and Steemers [25], as well as Kavgic et al. [52] all agree that the current shortcomings, which lie in the often missing quantification of inherent uncertainties and the lack in transparency of the models, must be resolved and that without rigorous testing the predictions of energy models run risk of lacking credibility.

The aim of this paper is, therefore, to provide a comparison of the accuracy and transferability of the twelve existing prediction models highlighted in Table 1 for determining a country's current and future energy demand in the residential sector. This is undertaken through objective analysis parameters, such as the relative deviation error, average percentage difference, Pearson's correlation coefficient r and the coefficient of determination r^2, taking Germany as a case study example. This includes a discussion of the present strengths and weaknesses of each model. The model comparison through objective analysis parameters furthermore gives an initial indication of the transferability of the models, most of which were not developed for the residential sector in Germany. In addition, through a sensitivity analysis of each model, the relevance of the input parameters of these twelve energy models is being assessed.

[1] Note: For evaluating the model outputs presented here the term "energy use" denotes the statistically determined use of energy in the past, whereas "energy demand" specifies the future energy needs on the basis of the modelling. This distinction follows the recommendations by Chateau and Lapillonne [27].

[2] Note: Up to reunification in 1990 these regulations were only valid in the western part of the country. In East Germany the corresponding regulations were TGL 28706 "Bautechnischer Wärmeschutz" (Structural Heat Insulation) that was legally binding from 1976 to 1981 and TGL 35424 "Bautechnischer Wärmeschutz" (Structural Heat Insulation) from 1981 onwards.